

## FILM BULK ACOUSTIC RESONATOR FILTER

This is a Division of U.S. Application No. 10/380,985  
filed March 20, 2003, which in turn is a U.S. National Stage  
5 Application of PCT/GB01/03141 filed July 11, 2001. The  
entire disclosure of the prior application(s) is hereby  
incorporated by reference herein in its entirety.

## BACKGROUND OF THE INVENTION

## 10 1. Field of the Invention

The present invention relates to a film bulk acoustic  
resonator (FBAR) filter, and more especially to an FBAR  
filter operating at microwave frequencies which can be  
simply fabricated using thin film technologies.

## 15 2. Description of the Related Art

It is important to prepare filters at high frequency in  
the MHz or GHz region because those frequency regions are  
often used for wireless communications these days. For such  
applications it is important that the filter is as small  
20 size as possible. Therefore, filter configurations are  
demanded which minimise the size of the filter on the  
substrate surface.

FBARs are attractive devices since they show resonant  
peaks at high frequency particularly in the MHz and GHz  
25 regions. Moreover, FBARs can be achieved in a small device  
(size ~100 microns). Thus, they are considered to be useful

for installation in small, light, thin electric appliance products, such as mobile phones.

FBARs are fabricated by depositing thin film piezoelectric layers, typically zinc oxide (ZnO), aluminium  
5 nitride (AlN) or lead zirconium titanate (PZT) onto a membrane or acoustic quarter wavelength stack formed on a semiconductor substrate. This combination forms an acoustic structure which is resonant at a specific frequency.

Prior art FBAR devices are coupled to associated  
10 circuitry by means of contact pads and wire bonds. This method provides a poorly defined ground connection because of the parasitic inductance of the wire leads. This approach also makes simulations and analysis of results difficult.

An alternative approach of incorporating the FBAR  
15 within a coplanar waveguide (CPW) structure involves the signal connection of the ground-signal-ground connection making contact to the top and bottom of the piezoelectric layer. In the known arrangement the electrodes are separate from the transmission line structure. This increases the  
20 area and limits the size of device that can be produced.

#### OBJECT AND SUMMARY OF THE INVENTION

It is an object of the invention to provide a film bulk acoustic resonator filter which is small in size and easy to  
25 fabricate.

A first film bulk acoustic resonator filter of the invention comprises a plurality of film bulk acoustic resonators each having a top electrode, a bottom electrode, and a piezoelectric layer sandwiched between the top and bottom electrodes, wherein the top electrodes of at least two of the film bulk acoustic resonators are connected to associated circuitry.

In the first film bulk acoustic resonator filter of the invention, the top electrodes of the at least two of the film bulk acoustic resonators connected to the associated circuitry may form part of transmission lines of a coplanar waveguide structure.

In the first film bulk acoustic resonator filter of the invention, the at least two of the film bulk acoustic resonators with the top electrodes connected to the associated circuitry may have a common bottom electrode.

A second film bulk acoustic resonator filter of the invention is a ladder-type film bulk acoustic resonator filter comprising at least two series resonators and at least two parallel resonators, each made of a film bulk acoustic resonator having a top electrode, a bottom electrode, and a piezoelectric layer sandwiched between the top and bottom electrodes, wherein the top electrodes of two of the series resonators are connected to associated circuitry.

In the second film bulk acoustic resonator filter of the invention, the top electrodes of the two of the series resonators connected to the associated circuitry may form part of a signal line of a coplanar waveguide transmission  
5 line.

In the second film bulk acoustic resonator filter of the invention, the two of the series resonators with the top electrodes connected to the associated circuitry may have a common bottom electrode.

10 By configuring the filter as a CPW structure, a compact filter is obtained that is not susceptible to stray parasitic effects. Furthermore, incorporating the filter within the coplanar transmission line structure eliminates the need for wire bonds, thereby simplifying fabrication.

15 Preferably the filter is a ladder filter in which the series FBARs form one group and the parallel FBARs form another group. The advantage of the ladder filter configuration is that additional passive capacitance and inductors that take up additional area are not required.  
20 Generally speaking, for a band-pass filter, the rejection level compared to the signal-pass area improves when more FBARs are used in the filter. According to the present invention, there is provided a filter made up of a plurality of FBARs which is small in size and shows low close-in  
25 rejection and low out-of-band rejection.

Typically, the series FBARs have identical areas and thicknesses and similarly the parallel FBARs have identical areas and thicknesses although both area and thickness can be different for the series and parallel FBARs. Identical series FBAR will be referred to as an "A" type FBAR, identical parallel FBARs will be referred to as a "B" type FBAR.

The series and parallel FBARs may be arranged in an ABAB sequence or in an ABBA sequence. The ABAB configuration in a CPW structure takes up more area compared to the ABBA configuration and adopting the ABBA configuration enables full use to be made of the device area.

The ABBA configuration within a CPW is also well suited to simple fabrication of a miniature filter using thin film technology and also allows easy fabrication of higher order filters without having to pattern the piezoelectric layer.

The FBARs may be positioned without air-bridges or metal tracks formed over the edge of the piezoelectric layer.

Advantageously, the piezoelectric material for the piezoelectric layer is selected from the group comprising zinc oxide, aluminium nitride, lead titanate zirconate, lead scandium tantalum oxide and bismuth sodium titanium oxide.

When the piezoelectric layer is ferroelectric, it is preferable to provide access to electrodes for poling the piezoelectric layer.

In the present invention, the top electrode of each series FBAR may form part of a signal line of a coplanar waveguide structure and the top electrode of each parallel FBAR may form part of a ground line of the coplanar waveguide structure. Preferably, the signal line is positioned between two ground lines.

According to the present invention, it is possible to implement a film bulk acoustic resonator filter which is small in size and easy to fabricate.

Other and further objects, features and advantages of the invention will appear more fully from the following description.

#### BRIEF DESCRIPTION OF THE DRAWINGS

In FIG. 1, (A) is a top view of an FBAR and (B) is a cross-sectional view of the FBAR shown in (A).

FIG. 2 is a schematic diagram of an ABAB ladder filter.

FIG. 3 is a schematic diagram of an ABBA ladder filter.

FIG. 4A is a top view of a ladder filter according to a first embodiment of the invention having the ABBA configuration shown in FIG. 3.

FIG. 4B shows the bottom electrode of the ABBA ladder filter shown in FIG. 4A.

FIG. 4C shows the top electrode for the parallel FBARs of the ABBA ladder filter shown in FIG. 4A.

FIG. 4D shows the top electrode for the series FBARs of the ABBA ladder filter shown in FIG. 4A.

FIG. 5A is a top view of a ladder filter according to a second embodiment of the invention having the ABAB configuration shown in FIG. 2.

FIG. 5B shows the bottom electrode of the ABAB ladder filter shown in FIG. 5A.

FIG. 5C shows the top electrode for the parallel FBARs of the ABAB ladder filter shown in FIG. 5A.

FIG. 5D shows the top electrode for the series FBARs of the ABAB ladder filter shown in FIG. 5A.

FIG. 6A and FIG. 6B show modelled comparisons of the S-parameters of the ABAB and ABBA ladder filters shown in FIG. 4A and FIG. 5A.

FIG. 7A is a top view of an ABBA ladder filter similar to FIG. 4A with ferroelectric layers according to a third embodiment of the invention.

FIG. 7B shows the bottom electrode of the ABBA ladder filter shown in FIG. 7A.

FIG. 7C shows the top electrode for the parallel FBARs of the ABBA ladder filter shown in FIG. 7A.

FIG. 7D shows the top electrode for the series FBARs of the ABBA ladder filter shown in FIG. 7A.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Embodiments of the invention are now described in more detail, by way of example only, with reference to the accompanying drawings.

Referring first to FIG. 1(A) and FIG. 1(B), a top view  
5 and a cross-sectional view of a standard FBAR are shown. The FBAR is arranged on the signal line of a ground-signal-ground line of a coplanar transmission line.

The device is configured for 2-port measurements so ground probes can be positioned at either end of ground  
10 electrodes 27, one signal probe can be positioned through a contact hole 26 onto the bottom electrode 25, and the other signal probe can be positioned at the end of the top electrode 24.

The dimensions of the coplanar transmission lines are  
15 designed to provide the system with a 50 ohm environment however there is enough design flexibility to allow the distance between ground and signal lines to be altered to accommodate FBARs of varying area while minimising the overall size of the FBAR and FBAR filter.

20 The FBAR consists of a continuous piezoelectric layer 23 deposited on an insulating layer 22. An input electrode which forms the bottom electrode 25 of the FBAR is formed on the insulating layer 22 and is configured as part of the signal line of a coplanar transmission line.

25 The region of overlap of the signal line defined on the insulating layer 22 and that part of the signal line defined

on the top of the piezoelectric layer 23 is positioned above the opening 28 in the substrate 20. The opening 28 is prepared by etching using backside pattern 21.

The output transmission line extends to measurement  
5 points or to other FBARs arranged in a ladder configuration. Using a continuous piezoelectric thin film, the input and output electrode must be defined before and after the deposition of the piezoelectric thin film. When the top electrode 24 is prepared, two ground electrodes 27 are  
10 prepared at the same time so that the top electrode 24 has a coplanar waveguide structure for which the characteristic impedance is set to about 50 ohms.

Access to the bottom electrode 25 of the FBAR for measurements is achieved by etching a contact hole 26. The  
15 size of the working area, which is equal to the centre part of the top electrode 24 and the bottom electrode 25, is typically 50-200 microns square for ZnO and 20-45 microns square for PZT.

FIG. 2 and FIG. 3 are schematic views of two  
20 arrangements of series and parallel FBARs to form ladder filters. Each filter comprises two FBARs in series and two FBARs in parallel. Such filters are referred to by a common nomenclature, as 2x2 ladder filters where the first numeral refers to the number of series resonators and the second  
25 numeral to the number of parallel resonators. For convenience herein, the series resonators will be denoted A

and the parallel resonators B. The series resonators A may often differ in area and thickness from the parallel resonators B. All series resonators A are identical and all parallel resonators B are identical.

5       The arrangement of FBARs in FIG. 2 and FIG. 3 differ in terms of the grounding sequence. The arrangement in FIG. 2 is here referred to as ABAB whereas that in FIG. 3 is referred to as the ABBA configuration with these terms describing the sequence of the series and parallel  
10 resonators.

      The realisation of the 2x2 filter in the ABBA coplanar configuration shown in FIG. 3 is illustrated in FIGS. 4A-D with dimensions suitable for a ZnO piezoelectric layer 23 while that of the 2x2 filter in ABAB coplanar configuration  
15 shown in FIG. 2 is illustrated in FIGS. 5A-D.

      In either of the two examples, the top electrodes 24 and 27 form part of transmission lines of the coplanar waveguide structure. The top electrodes 24 and 27 are connected to associated circuitry. At least two of the  
20 FBARS in which the top electrodes are connected to the associated circuitry have the common bottom electrode 25. Moreover, in either of the examples, the top electrodes 24 of the two series FBARs 10 form part of a signal line of the coplanar waveguide transmission line. The signal line is  
25 positioned between the two ground electrodes 27. The top electrodes 24 of the two series FBARs 10 are connected to

the associated circuitry. The two series FBARs 10, which are connected to the associated circuitry via the top electrodes 24, have the common bottom electrode 25.

The series FBARs 10 and the parallel FBARs 11 are  
5 positioned on a single membrane structure. The invention simplifies the processing considerably and eliminates the need to pattern by etching the ZnO piezoelectric layer 23. For the ABBA and ABAB configurations within a coplanar transmission line, one layer forms the bottom electrode 25  
10 of all four FBARs that make up the 2x2 filter.

As a result of using ABBA configured filter within CPW, certain orders of ladder filters, in which the number of parallel FBARs is equal or bigger than that of the series FBARs, such as ABBABBA (3/4), ABBABBAA (4/4) are easier to  
15 fabricate within a CPW.

For filters with ABAB configuration in simple CPW, it is difficult to fabricate filters with the same number of series and parallel FBARs, such as ABABAB (3/3) without forming piezoelectric mesas by etching. A mesa is necessary  
20 to be able to run a top electrode metal pattern down the side of the piezoelectric material in an FBAR so that it can form the bottom electrode of the following FBAR. Only filters with the number of parallel FBARs less than the number of series FBARs, such as ABAAB (3/2), can be  
25 fabricated without piezoelectric material etching.

The ABBA structure can be used in other waveguide configurations, for example, microstrip, but a greater area is taken up by the filter than when used in the ABAB configuration. For an ABBA filter within a microstrip, a transmission configuration for an electrode to be able to connect a top electrode on the piezoelectric material to a bottom electrode on the next FBAR necessitates etching a piezoelectric mesa or the use of air-bridge technology.

The top surface fabrication sequence for the filter containing 4 FBARs arranged in the ABBA configuration shown in FIG. 4A is now described. First the bottom electrode metallised pattern is defined by prior art fabrication techniques. A piezoelectric layer is then deposited over the whole surface.

The filter is then completed by depositing either one or two top electrode metallised patterns depending on whether different metal thickness and hence different frequencies are required for the series and parallel FBARs in accordance with prior art.

The final fabrication stage is the formation of the opening under insulating layer 22 by the techniques of bulk silicon etching or deep reactive etching as well known by those versed in the art.

The fabrication steps for the ABAB filter shown in FIG. 5A are similar to those for the ABBA configuration, although the order of layer fabrication varies.

The through coefficient ( $S_{21}$ ) of 2x2 ZnO FBAR filters having the ABAB and ABBA configurations are compared in FIGS. 6A, 6B. The filters have the same insertion loss and little difference in the out-of-band rejection. The ABAB  
5 configuration has greater close-in rejection, sharper roll-off and slightly larger bandwidth than that obtained from the ABBA configuration. The ABBA configuration can have a flatter pass-band.

A further embodiment of 2x2 ladder filter according to  
10 the invention for use with piezoelectric layers 23 that are also ferroelectric and so need to be poled is shown in FIGS. 7A-D. The fabrication procedure is identical to that for the ZnO FBAR filters described above except that a contact hole 26 is made to the common bottom electrode 25. Using  
15 this contact hole, 26, for poling in the ABBA configuration allows access to the common bottom electrode 25 eliminating the need to make multiple bottom electrode connections on a single filter. With the ABAB configuration, extra contact holes are needed for poling.

20 Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.